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BASIC STUDIES IN COMBINATORIAL AND NONDIFFERENTIABLE OPTIMIZATI--ETC(U)
MAR 78 J F SHAPIRO

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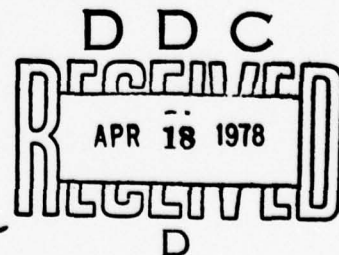
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OPERATIONS RESEARCH CENTER

Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

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July 1, 1976 through June 30, 1977



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I. INTRODUCTION

The Operations Research Center conducts interdepartmental academic and research programs in operations research. The academic staff of the Center is drawn from many departments, including Sloan School of Management, Urban Studies and Planning, Electrical Engineering and Computer Science, Aeronautics and Astronautics, and Physics. At present, approximately 18 students are in the operations research doctoral program and a comparable number are in the master's program. Most of them come to M.I.T. specifically to study operations research and are admitted directly by the Center, although some learn about the graduate operations research programs by attending seminars or subjects.

During the past year, the academic staff of the Center have engaged in a wide range of research activities sponsored directly by the Center. There was basic research into the methodologies underlying operations research including mathematical programming, decision analysis, and probabilistic models. There was also a variety of model building and applications-oriented research using these methodologies.

Basic research into the mathematics of operations research received continued strong attention. Developments included further work on integer programming duality theory, arising from the implementation of the theory and its use on a variety of integer programming problems. Additional basic research in discrete optimization and network optimization was performed. Research was completed on the modeling and analysis of decision problems where alternatives have consequences to each of a collection of individuals or interest groups. Research in robust estimation and the sensitivity analysis of econometric models was continued.

An applied research project studying public attitudes and decision processes with regard to blood donation entered its final year. The work concentrated on issues such as the effects of the collecting organization's ideology on donor selection and on donor's "reasons" for giving, the spread of donor activity and blood knowledge in the population, and the circumstances under which donors become exdonors. Findings are that the blood supply and the willingness of the public to participate in it are much better than is generally assumed.

A one-year project to evaluate the consumer's interest in automobile insurance merit-rating plans was carried out during 1976-77. Merit-rating plans were analyzed in order to recommend minimum standards for such plans, to estimate the impact that

such plans might have on the total cost of insurance premiums and the distribution of these costs among Massachusetts motorists, to determine data requirements for evaluating the effectiveness of such plans and to identify conditions under which "merit rating" is a desirable means of distributing accident costs.

Joint applied research with the Center for Transportation Studies entered its second year. Results included extensions of the uni-modal traffic equilibrium model to the multi-modal case, including generalizations of demand functions for traffic flow, new existence theorems about equilibria and algorithms for solving the multi-modal problem. Other research performed on this project was directed at problems of train operations including a study of train formations and work allocations among train years. Finally, there was continuing work on algorithms for network design and location problems.

A long-term project on multi-level logistics systems received continued support and attention. Decomposition methods were devised and tested to partition, link, aggregate and disaggregate large scale production, inventory and distribution systems. Applications were made to several industrial production planning problems.

Modeling and analysis of urban vehicular services also continued during the past year. There were extensions and new implementations of the hypercube queuing model for facility location and redistricting in urban emergency services. Other research included: random walk models of servers in emergency vehicles, quantitative models for describing and controlling clumping in buses, an optimal delay study of transit vehicles at transfer points, network analysis and Markovian decision models for the dynamic relocation of mobile servers. In addition, research was begun in the new area of quantitative techniques for the evaluation of public programs.

An important new area of theoretical and applied research during the past year has been in the use of operations research models and methods in economic planning problems. Basic research was completed on the mathematical structure and solution of economic equilibrium problems arising in energy and traffic modeling. Collaborative research was begun with Brookhaven National Laboratory on the extension and analysis of the Brookhaven Energy System Optimization Model which is a linear programming representation of the U.S. energy sector in selected years in the future. A simplified version of this model was used in a separate study of the optimal use of depletable resources. Other economic planning problems, studied during the past year, included the determination

of government subsidies for economically depressed areas and optimization models for planning economic development.

Operations Research Center staff and students were involved in a variety of research activities with other departments and centers both within and outside M.I.T. For example, several students and staff were involved in a study at the M.I.T. Energy Laboratory of the effectiveness of technical and institutional R&D initiatives in improving light water moderated nuclear reactors. Research continued at the Energy Laboratory on a probabilistic model of the oil and gas exploration process that constitutes a component of an economic supply function for petroleum reserves from new discoveries. Staff and students were also involved in traffic studies at the Electronic Systems Laboratory and in an earthquake study in the Department of Civil Engineering.

Several members of the Operations Research Center staff were active in research programs at the National Bureau of Economic Research Computer Research Center for Economics and Management Science located in Cambridge, Massachusetts. Their activities included development of interactive computer systems for linear and integer programming and methods of robust estimation. The computer tools developed at the Computer Research Center are publicly available and have been used on many applications of the research projects mentioned previously.

Support for the Center's research during the past year has come from the Army Research Office, the Public Health Service, the Massachusetts Automobile Rating and Accident Prevention Bureau, the U.S. Department of Transportation and the Office of Naval Research.

Jeremy F. Shapiro
Acting Director

II. RESEARCH ACTIVITIES

1. Mathematical Methods

1.1 Mathematical Programming and Optimal Control

Staff Reports

T. HANSEN, The Derivation of Efficient Sets, M.I.T. Operations Research Center Working Paper OR 062-77, March 1977.

This paper presents an algorithm that solves the parametric quadratic programming problem:

$$\begin{aligned} &\text{maximize} \quad -\frac{1}{2} X'AX, \\ &\text{subject to} \quad BX \leq D, \\ &\quad \quad \quad -C'X \leq -R, \\ &\quad \quad \quad X \geq 0. \end{aligned}$$

for all R between R_{\max} and R_{\min} .

The algorithm thus generates the set of efficient portfolios in the portfolio allocation problem. The algorithm essentially involves the solution of one quadratic programming problem and then one addition pivot step in the linear programming sense for each corner portfolio. A numerical example is given.

A.C. HAX, On the Solution of Convex Knapsack Problems with Bounded Variables, (with G.R. Bitran), M.I.T. Operations Research Center Technical Report No. 129, April 1977.

A recursive method to solve separable differentiable convex knapsack problems with bounded variables is presented. The method differs from classical optimization algorithms of convex programming and determines at each iteration the optimal value of at least one variable. Applications of such problems are frequent in resource allocation and recently have shown to be useful in hierarchical production planning. Computational results are presented.

RESEARCH ACTIVITIES: Mathematical Methods

J.D.C. LITTLE, Optimal Adaptive Control: A Multivariate Model for Marketing Applications, IEEE Transactions on Automatic Control, Vol. AC-22, No. 2, April 1977, pp. 187-195.

Marketing applications motivate a specialized model and its adaptive control. Each of r control variables is set in each of a sequence of time periods. The process being controlled has a response (profit) function that is the sum of a constant plus linear and quadratic forms in the control variables. The coefficients of the quadratic form are assumed to be known constants, those of the linear form to change with time as first-order autoregressive processes. Information about the changing coefficients is collected by performing a 2^r factorial experiment on a subportion of the process being controlled. Provision is made for adding further information from unspecified sources. Bayesian methods update the distributions of the unknown coefficients. Dynamic programming determines the values of the control variables and experimental design parameters to maximize the sum of discounted future profits. The probabilistic assumptions of the model are chosen so that all distributions are normal with known variances and, for the most part, zero covariances between variables. Partly as a result of this, optimal control turns out to involve rather simple exponential smoothing rules.

T.L. MAGNANTI and J.F. SHAPIRO, Generalized Linear Programming Solves the Dual, (with M.H. Wagner), Management Science, 22, No. 11, July 1976, pp. 1195-1203.

The generalized linear programming algorithm allows an arbitrary mathematical programming minimization problem to be analyzed as a sequence of linear programming approximations. Under fairly general assumptions, it is demonstrated that any limit point of the sequence of optimal linear programming dual prices produced by the algorithm is optimal in a concave maximization problem that is dual to the arbitrary primal problem. This result holds even if the generalized linear programming problem does not solve the primal problem. The result is a consequence of the equivalence that exists between the operations of convexification and dualization of a primal problem. The exact mathematical nature of this equivalence is given.

T.L. MAGNANTI, Duality and Sensitivity Analysis for Fractional Programs, (with G.R. Bitran), Operations Research, 24, No. 4, 1976, pp. 675-699.

Algorithms, duality and sensitivity analysis for optimization problems, called fractional, whose objective function is the ratio of

RESEARCH ACTIVITIES: Mathematical Methods

two real valued functions are considered. A procedure, suggested by Dinkelbach for solving the problem, its relationship to certain approaches via variable transformations, and a variant of the procedure which has convenient convergence properties are discussed. The duality correspondences that are developed do not require either differentiability or the existence of optimal solution. The sensitivity analysis applies to linear fractional problems, even when they "solve" at an extreme ray, and includes a primal-dual algorithm for parametric right-hand-side analysis.

T.L. MAGNANTI, The Structure of Admissible Points with Respect to Cone Dominance, (with G.R. Bitran), Discussion Paper 7716, Center for Operations Research and Econometrics, Heverlee, Belgium, June 1977.

The set of admissible (pareto-optimal) points of a closed convex set X when preferences are described by a convex, but not necessarily closed, cone are studied. Assuming that the preference cone is strictly supported and making mild assumptions about the recession directions of X ,

(i) a representation theorem of Arrow, Barankin and Blackwell is extended by showing that all admissible points are either limit points of certain "strictly admissible" alternatives or translations of such limit points by rays in the closure of the preference cone, and

(ii) it is shown that the set of strictly admissible points is connected, as is the full set of admissible points.

Relaxing the convexity assumption imposed upon X , local properties of admissible points in terms of Kuhn-Tucker type characterizations are considered. Necessary and sufficient conditions are specified for an element of X to be a Kuhn-Tucker point, conditions which, in addition, provide local characterizations of strictly admissible points.

S.K. MITTER, Lagrange Duality Theory for Convex Control Problems, (with W.W. Hager), Journal of Control and Optimization, 14, August 1976, pp. 843-856.

The Lagrange dual of control problems with linear dynamics, convex cost, and convex inequality state and control constraints is analyzed. If an interior point assumption is satisfied, then the existence of

RESEARCH ACTIVITIES: Mathematical Methods

a solution to the dual problem is proved and if there exists a solution to the primal problem, then a complementary slackness condition is satisfied. A necessary and sufficient condition for feasible solutions in the primal and dual problems to be optimal is also given. The dual variables p and v corresponding to the system dynamics and state constraints are proved to be of bounded variation while the multiplier corresponding to the control constraints is proved to lie in L^1 . Finally, a control and state minimum principle is proved. If the cost function is differentiable and the state constraints have two derivatives, then the state minimum principle implies that a linear combination of p and v satisfy the conventional adjoint condition for state constrained control problems.

S.K. MITTER, Exact Solution to Lyapunov's Equation Using Algebraic Methods, (with T.E. Djaferis), Proceedings of the 1976 Conference on Decision and Control Including the 15th Symposium on Adaptive Processes, December 1976, pp. 1194-1200.

Let $A'P + PA = -Q$ be a Lyapunov equation with A being a stability matrix and both A and Q matrices with rational entries. Multiplying A and Q by a suitable positive integer an equivalent Lyapunov equation $A_1'P + PA_1 = -Q_1$ is obtained, with A_1 and Q_1 having integer entries. Let $I(x,y)$ be the ring of polynomials in x and y over the integers I , and E be the set of all square matrices with integer entries. The solution P to this equation is given by:

$$P_u = (e_{mn}) = f_{A_1}(q_u(x,y), Q_1)$$

$$P = \frac{1}{u^2} \cdot P_u$$

where: $q_u(x,y) \in I(x,y)$ and $u \in I$

$$f_{A_1} : I(x,y) \times E \rightarrow E \text{ defined as } f_{A_1}(h(x,y), M)$$

$$= \sum_{j,k} h_{jk}(A_1')^j \cdot M \cdot A_1^k$$

which is a finite sum.

RESEARCH ACTIVITIES: Mathematical Models

The calculation of u and $q_u(x,y)$ requires finding the characteristic polynomial of A_1 , as well as using the Euclidean Algorithm, computations which lead to polynomial coefficient growth. In order to eliminate the space consuming manipulation of large integers in intermediate steps, modular arithmetic is used to obtain the matrix $P_u = (e_{mn} \bmod p_i)$ and $p_i u = u \bmod p_i$ with p_i a prime, for a sufficient number of primes. The Chinese Remainder Theorem is then applied to obtain the solution P .

The algorithm has been programmed on MACSYMA which is a very suitable computer programming system for all the numerical computations involved.

Numerical results as well as extensions to solving the Algebraic Riccati Equation are presented.

S.K. MITTER, An Example of an Infinite Dimensional Filtering Problem: Filtering for Gyroscopic Noise, (with L. Horowitz), Proceedings of the 1976 Conference on Decision and Control Including the 15th Symposium on Adaptive Processes, December 1976, pp. 764-773.

An infinite-dimensional model is given for the generation of gyroscopic noise, which exhibits power spectral density proportional to $(1/f)$ over a wide frequency range. The optimal filter is given for separating a statistically described signal from additive gyroscopic noise, using discrete-time observations. This filter is expressed as a discrete-time infinite-dimensional Kalman-Bucy filter, with an associated Riccati covariance operator equation. Sufficient conditions are specified such that this Kalman-Bucy filter will possess various desired properties.

J.F. SHAPIRO, A New Constructive Duality Theory for Mixed Integer Programming, Symposia Mathematica, Volume XIX, Copenago Dell'Aprile 1974, Academic Press, 1976, pp. 61-71.

This paper shows how duality theory for pure integer programming can be combined with Benders' method for mixed integer programming. The resulting mixed integer dual problem provides stronger lower bounds than the linear programming lower bounds.

J.F. SHAPIRO, A Note on the Primal-Dual and Out-of-Kilter Algorithms for Network Optimization Problems, Networks, January 1977, pp. 81-88.

This paper compares and contrasts two distinct primal-dual methods to network optimization, including the out-of-kilter method. A hybrid approach combining the two methods is suggested.

RESEARCH ACTIVITIES: Mathematical Methods

J.F. SHAPIRO, A Survey of Lagrangean Techniques for Discrete Optimization, M.I.T. Operations Research Center Technical Report No. 133, May 1977.

This survey covers the theory and application of Lagrangean techniques to discrete optimization problems. A discussion of the applications includes integer programming special structures which can be exploited by Lagrangean techniques, multi-item production scheduling and inventory control problems, and the traveling salesman problem. The relationship of Lagrangean techniques to duality theory and convex analysis is given including a discussion of algorithms to solve the dual problems. Duality theory for integer programming and its relationship to the cutting plane method is reviewed. The use of Lagrangean techniques in conjunction with branch and bound is presented in a general framework for solving discrete optimization problems.

J.F. SHAPIRO, A Convergent Duality Theory for Integer Programming, (with D.E. Bell), Operations Research, 25, No. 3, May-June 1977, pp. 419-434.

A constructive procedure for generating a finite sequence of increasingly stronger dual problems to a given integer programming problem is presented. The last dual problem in the sequence yields an optimal solution to the integer programming problem. It is shown that this dual problem approximates the convex hull of the feasible integer solutions in a neighborhood of the optimal solution it finds. The theory is applicable to any bounded integer programming problem with rational data.

1.2 Decision Analysis, Statistics and Stochastic Systems

Staff Reports

S. PARIENTE and R.E. WELSCH, Ridge and Robust Regression Using Parametric Linear Programming, M.I.T. Sloan School of Management Working Paper 899-77, January 1977.

Two new regression techniques are beginning to have a major impact on statistics -- ridge regression and robust regression. There is a form of duality in these ideas -- robust procedures try to determine if some data points should be given less influence while ridge

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procedures give less weight to certain linear combinations of the independent variables or carriers. In this paper, several ways are presented to combine ridge and robust regression.

R.E. WELSCH, Techniques for Nonlinear Least Squares and Robust Regression, (with J.E. Dennis), 1976 Proceedings of the ASA Statistical and Computing Section, American Statistical Association, Washington, D.C., August 1976, pp. 83-87.

Chambers suggested that the following algorithms, in decreasing order of importance, should be part of the statistician's equipment:

- (i) a recent quasi-Newton (QN) method with a provision for difference approximations to derivatives
- (ii) a search and simplex procedure
- (iii) a special routine for nonlinear least-squares (NLLS)
- (iv) a Newton-Raphson method, for models with inexpensive second derivatives.

The routine usually suggested for (iii) is a version of the Gauss-Newton-Levenberg-Marquardt (GNLM) method.

The experience of the authors has been that when faced with a NLLS problem (iii) is tried, but too often fails, forcing them to use (i) which, unfortunately, does not take any advantage of the special structure of the NLLS problem. This paper presents the outlines of a class of algorithms to replace GNLM for (iii) that take advantage of special structure and have the reliability usually associated with a QN method. Also discussed is how the new algorithms can be modified for use on nonlinear robust regression problems.

R.E. WELSCH, Comparing Relative and Total Cost Multiple Comparison Procedures via James-Stein Estimators, M.I.T. Sloan School of Management Working Paper 892-76, December 1976.

In a recent panel discussion on multiple comparison (MC) procedures, a question was raised about the advisability of journals requiring that certain specific MC procedures be used in the papers they published. The consensus seemed to be that while a journal might consider proposing standards it should in no way inhibit the use of other procedures which the author might consider more suitable to his/her problem.

RESEARCH ACTIVITIES: Mathematical Methods

It is proposed in this paper that instead of standardized procedures, the journals recommend that, where possible, the costs (losses) associated with a particular MC procedure be stated in at least two ways - total and relative.

The first way emphasizes the total cost of type 1 (1 and/or 3) errors (conversely type 2 errors) and is associated with control of the experiment-wise error rate (α) for all hypotheses containing groups of equal (or for type 3, nearly equal) population means. (Of course, this does not control the total cost of type 1 and 2 errors which increases with the number of populations considered.)

The second way focuses on the relative cost of type 1 and type 2 errors and has been most frequently associated with tests proposed by Waller and Duncan.

There are at least three basic approaches to inference in the MC situation; Bayesian (B), James-Stein or empirical Bayes (JS), and maximum likelihood (ML). It is important, at least in the beginning, to separate discussions of cost from questions of inference. This has not often been done in the past and total cost seems to be limited to ML methods while relative costs are linked to the JS and B methods.

R.E. WELSCH, The Hat Matrix in Regression and ANOVA, (with D.C. Hoaglin), M.I.T. Sloan School of Management Working Paper 901-77, January 1977.

In fitting linear models by least squares it is very often useful to determine how much influence or leverage each data y-value (y_i) can have on each fitted y-value (\hat{y}_j). For the fitted value \hat{y}_i corresponding to the data value y_i , the relationship is particularly straightforward to interpret, and it can reveal multivariate outliers among the carriers (or x-variables) which might otherwise be difficult to detect. In a regression problem the desired information is available in the "hat matrix", which gives each fitted value \hat{y}_i as a linear combination of the observed values y_j . (The term "hat matrix" is due to John W. Tukey, who introduced us to the technique about ten years ago.) The present paper derives and discusses the hat matrix and gives several examples which illustrate its usefulness.

RESEARCH ACTIVITIES: Mathematical Methods

R.E. WELSCH, Linear Regression Diagnostics, (with E. Kuh), M.I.T. Sloan School of Management Working Paper 923-77, April 1977.

This paper attempts to provide the user of linear multiple regression with a battery of diagnostic tools to determine which, if any, data points have high leverage or influence on the estimation process and how these possibly discrepant data points differ from the patterns set by the majority of the data. The point of view taken is that when diagnostics indicate the presence of anomolous data, the choice is open as to whether these data are in fact unusual and helpful, or possibly harmful and thus in need of modifications or deletion.

The methodology developed depends on differences, derivatives, and decompositions of basic regression statistics. There is also discussion of how these techniques can be used with robust and ridge estimators. An example is given showing the use of diagnostic methods in the estimation of a cross-country savings rate model.

Student Reports

S.E. BODILY, Collective Choice with Multidimensional Consequences, M.I.T. Operations Research Center Technical Report No. 127, July 1976.

This work considers decision problems where alternatives have consequences to each of a collection of individuals or interest groups. It contributes to both the theoretical understanding of collective choice problems and to the development of a methodology for aggregating consequences.

A taxonomy of collective choice formulations provides the context for contrasting a surrogate utility formulation, explored in this work, with other approaches. With x_j^i the consequence to individual i measured by numeraire j , the surrogate utility function (SUF) provides a cardinal ranking of alternatives by aggregating $\{x_j^i, i = 1, 2, \dots, n, j = 1, 2, \dots, m\}$ into a scalar.

Two aggregate schemes for SUF are studied. 1) Personal preference aggregation (PPA) aggregates first over j for each individual and then over individuals. 2) Numeraire aggregation (NA) aggregates first over i for each numeraire and then over numeraires. Motiva-

RESEARCH ACTIVITIES: Mathematical Methods

tion and mathematical forms for the SUF under each aggregation scheme are given. When individual preferences are used to aggregate the elements in each row, we verify that Arrow-like normative conditions can be satisfied. Several models are given for assigning the parameters of the SUF, including a participatory model for achieving consensus. A methodology for direct assessment of preferences is developed and the rationale is presented for making the necessary interpersonal comparisons of consequences.

New theoretical results are obtained for state-dependent utility functions, where consequences to a subgroup of individuals are not utility separable from consequences to others, but rather depend on a state descriptor of others' consequences. The axiomatic bases for several forms of a state-dependent SUF are derived.

Under NA, a normative methodology for ranking interpersonal dispersions to consequences is provided and its advantages relative to traditional ad hoc approaches to measuring inequality is indicated. When distributional judgments are made in conditions of uncertainty, a dilemma arises concerning whether prior or posterior equality (or equity) is desired. A state-dependent SUF is used to resolve the dilemma.

RESEARCH ACTIVITIES

2. Models and Applications

2.1 Urban and Other Public Systems

Staff Reports

A.W. DRAKE, Getting People to Give Blood: Ideologies, Practices and Issues, M.I.T. Operations Research Center Technical Report No. 131, April 1977.

This report comments on the state of the blood supply and reviews some results of an M.I.T. project concerned with public attitudes and decision processes with regard to blood donation.

It begins with a review of some of the recent developments that have brought attention to the blood supply. A framework for the characterization of blood collection ideologies is presented, along with a discussion of several factors that make the practices of collection organizations more similar than their ideologies.

A summary of some preliminary results of the research work is given, suggesting that public reluctance with regard to blood donation is unlikely to be the primary limitation on the blood supply at the present time. After a personal assessment of the present state of the whole blood supply, a short list of primary concerns is suggested. These include the integrity of blood collection messages, the degree and style of government intervention in the blood supply, the development of larger gifts (pheresis donations) as a more common practice, and a careful determination of the degree to which the selection and timing of medical procedures are actually affected by the blood supply.

It is suggested that 1) the blood supply operates at a very high level of performance, 2) the organizational resources and skills of the collectors are the primary limitation on the supply at some critical times, and 3) public participation in the blood supply is at a far greater level than is generally acknowledged. It is argued that the primary reason "only" about 3.5% of the U.S. population (or about 10% of the eligible population) give blood in any one year is that this number of donors is generally adequate to meet medical needs.

RESEARCH ACTIVITIES: Models and Applications

J. FERREIRA, JR., Designing Equitable Merit Rating Plans, M.I.T. Operations Research Center Working Paper OR 057-76, August 1976.

Throughout the United States, it is common practice for automobile premiums for a particular policy to vary depending upon the driver class and geographic location of the policyholder as well as the type and number of vehicles covered by the policy. In addition, most states also permit so-called "merit rating" plans whereby each policyholder's annual premium is adjusted up or down depending upon the insured's claims experience and traffic violation record during the previous years. Although these merit rating plans may be viewed as a special type of risk classification, the rationale underlying their use is quite different from the justification for driver class and territory differentials. This paper develops a methodology for evaluating merit rating plans that are used in conjunction with other risk classification criteria. A theoretically equitable merit rating plan is designed and compared with plans commonly used throughout the country. The differences are striking, especially among high risk classes. For example, most typical merit rating plans overcharge good drivers in high risk classes -- often by more than 25%.

J. FERREIRA, JR., Observations on the Social Impact of Large Accidents, M.I.T. Operations Research Center Technical Report No. 122, October 1976.

Comparing the severity and frequency of occurrence of deaths due to fires, natural hazards, mining disasters, and transportation accidents suggests an unusual amount of consistency. Cumulative plots of severity and frequency for all these catastrophe types exhibit loglinear relationships with similar slopes. The empirical data indicate that there is a cubic relationship between severity and frequency of large accidents. The stochastic properties of these risks do not fully explain the observed patterns. The implied social preferences are interpreted in terms of a conventional "rational" economic model and an alternative "disaster" model. The role of perceptual distortions in risk assessment is considered.

R.C. LARSON, Evaluating a Police-Implemented AVM System: The St. Louis Experience (Phase I), (with K.W. Colton and G.C. Larson), IEEE Transactions on Vehicular Technology, Vol. VT-26, No. 1, February 1977.

The St. Louis Metropolitan Police Department is the first major urban police department to implement an automatic vehicle monitor-

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ing (AVM) system. The AVM technology incorporates computer-aided dead-reckoning, thus facilitating vehicle tracking on individual streets in a city. Implemented as a Phase I prototype system in one police district early in 1975, the test system is evaluated in this paper utilizing a three-pronged approach. Focusing on 1) technology, 2) police operations, and 3) attitudes and organizational impact, attention is given to operational performance in Phase I, to ameliorative action for Phase II, and to the affects of AVM on response time, officer safety, voice-band congestion, and command and control.

P.M. MORSE, Demand for Library Materials: An Exercise in Probability Analysis, M.I.T. Operations Research Center Working Paper OR 059-76, October 1976.

To evaluate the effect, on the use of library materials, of various possible changes in library policy on circulation rules, for example, or on the buying of duplicate copies, one must estimate the potential demand for the material, not just the actual use under existing policy. Although the concept of the potential demand, for a book for instance, is a rather vague one, this paper shows how it can be defined and evaluated in terms of the more definite and more easily measurable quantities, yearly circulation rate and mean local period for borrowed books. The estimates are statistical ones, the average demand per book, the probability that a book that circulates m times a year has a demand λ , etc. Graphs and Tables are given that show how these quantities can be evaluated once one knows the mean per book circulation and the mean length of time a book is out of the library per circulation, for a portion of the library that is fairly homogeneous in regard to use (such as all science books, or all biographies). The analysis is then used to show how one can, by the use of the tables and graphs, estimate how much a change in the allowed length of loan period will change the average per book circulation, or what the quantitative effect would be if duplicate copies were bought for all books that circulated more than m times, as well as other measures of library utility that depend on demand rather than directly on past circulation.

P.M. MORSE, A Queuing Theory, Bayesian Model for the Circulation of Books in a Library, M.I.T. Operations Research Center Working Paper OR 061-77, February 1977.

The use of library materials, the borrowing of books for example, is analogous to a queuing process, where an arrival is "serviced" when he finds a book on the shelf and borrows it; when service is

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busy the arrival is lost to the system. Circulation, rate of output of the service channel, can be measured for each book; the circulation distributions for a number of classes of related books (homogeneous collections) have been determined. Circulation rate can be changed by changing circulation rules, whereas the total rate of arrival for a book, whether "serviced" or not, is less affected by changes in rules. However, this total arrival rate (called demand rate) for a book, cannot be measured directly. This paper shows how its expected value may be calculated, using Bayes' theorem. From this, the paper develops a self-consistent model of book circulation, with inter-related probability distributions, from which one can predict the effect, on circulation, of a change in loan rules or of the purchase of duplicate copies of the more popular books, and also can measure the decline in demand for a book with time. Results check available data on six collections, in two libraries.

Student Reports

D.W. TALAFUSE, Blood Donor Attitudes and Decisions: An Exploratory Analysis, SM in OR Thesis, September 1976.

The author reports on a pretest survey activity performed with samples of frequent and apparent former blood donors associated with each of four central blood collection programs. The survey instrument utilized is a self-administered mail questionnaire, concentrating on aspects of the respondent's first and most recent blood donations, on knowledge and attitudes about blood policy, and on some demographic characteristics.

Topics studied include:

1. The development of a better understanding of factors associated with the ways individuals begin and cease donating. How "reasons" for first donations vary among four locations, among frequent and former donors, and how such reasons have been changing over time are considered. For the respondents, the lack of a perceived convenient donation opportunity is the single factor that best separates the frequent and former donors.
2. The relationship between blood collection systems and the attitudes and behavior of their participants. It was found that the ideology of individuals strongly reflects the ideology of their

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blood collector. It was found that the one community responsibility system in the study has as its most active donors people who donate much more frequently than is the case for the three individual responsibility systems. Surprisingly, little variation is found in the responses from each of the three individual responsibility systems. Donors from all systems speak very favorably of their most recent donation.

3. The ways in which male and female donors differ with regard to attitudes and donation behavior. Women are slightly more likely to give altruistic reasons for donation and they constitute a larger fraction of the ex-donors than of the frequent donors.
4. Consideration of several simple descriptive measures. It is noted, for example, that it is a consistent tendency for the average age at the time of first donation to increase over the last thirty years.

This report emphasizes the data analysis more than its possible interpretations. Several very important limitations on the results are noted. These include the complexity and low response rate associated with identifying and reaching former donors and the likely self-selection of respondents favoring people with positive dispositions toward the blood supply system.

2.2 Traffic and Transportation

Staff Reports

N.H. GARTNER and B.L. GOLDEN, Modeling and Optimization for Transportation Systems Planning and Operations, (with R.T. Wong), M.I.T. Operations Research Center Working Paper OR 056-76, July 1976.

This paper focuses on a number of applications of network optimization techniques to transportation systems analysis. In particular, network analysis problems, network design problems, and network management problems are discussed in some detail. The intent is to survey important application areas.

N.H. GARTNER and J.D.C. LITTLE, Steady State Traffic Optimization by MITROP, (with H. Gabbay), Proceedings of the IFAC/IFIP/IFORS Third International Symposium, August 1976, pp. 315-327.

MITROP (Mixed Integer Traffic Optimization Program) is a new computer program for traffic signal control in urban street networks.

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It is designed to optimize simultaneously all the traffic control variables of the network including cycle time, splits of green time, and offsets. Both deterministic and stochastic models are used to represent the traffic flow process. The optimization problem is formulated in terms of mixed-integer linear programming and a globally-optimal solution is determined via the MPSX optimization system. The method was applied to several signal-controlled traffic networks, for various demand patterns, and offers certain advantages over existing methods. In particular, it is shown that network performance is sensitive to variations in cycle time, which has to be determined in conjunction with all the other traffic control variables. The paper describes the application of the program to a section of the UTCS/BPS test network in Washington, D.C.

N.H. GARTNER and J.D.C. LITTLE, Simultaneous Optimization of Offsets, Splits, and Cycle Time, (with H. Gabbay), Transportation Research Record, No. 596, 1976, pp. 6-15.

Setting traffic signals in an urban street network involves the determination of cycle time, splits of green time, and offsets. All existing methods use a sequential procedure for calculating the traffic control variables. A common cycle time is established first, then green splits are calculated for each intersection, and, finally, offsets among the signals are determined. Because these three computation stages are not really independent, the results are often not optimal. This paper describes a new computer method, mixed-integer traffic optimization, designed to optimize simultaneously all the traffic control variables of the network. The method has been programmed in conjunction with the mixed-integer routine of IBM's MPSX optimization system and thus provides a globally optimal procedure. It was applied to several traffic signal networks and is shown to offer certain advantages over existing methods. An example is presented in the paper to illustrate the input requirements, output format, and application of the program.

J.D.C. LITTLE and N.H. GARTNER, Computer-Assisted Traffic Engineering Using Assignment, Optimal Signal Setting and Modal Split, (with S.B. Gershwin), M.I.T. Electronic Systems Laboratory Technical Report ESL-R-737, April 1977.

Methods of traffic assignment, traffic signal setting, and modal split analysis are combined in a set of computer-assisted traffic engineering problems. The system optimization and user equilibrium traffic assignments are described. Travel time functions

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are presented for freeways, freeway entrance ramps, and signalized streets. Both single-vehicle and multiple-vehicle-class formulations are described. In particular, cars, car pools, and buses are considered. Energy optimization is treated, and gasoline consumption functions for cars and buses are shown. Modal split analysis is described and integrated with the assignments. This way, the effect of favoring buses and car pools with "diamond lanes" can be measured. The procedures are described and numerical examples are presented. Some areas of required research are identified, and it is concluded that this approach to traffic engineering can be made practical.

A.R. ODONI, Estimates of Capacity and Delay for Proposed Runway Systems: Schiphol Airport, Amsterdam, (with R.W. Simpson), M.I.T. Flight Transportation Laboratory Technical Report R76-12, December 1976.

1. The addition of the fifth runway at Schiphol increases the airport hourly capacity for landings by almost 100%, and the capacity for takeoffs by more than 40%.
2. The current runway system will provide good levels of service (average delays less than 4 minutes, % aircraft delayed more than 20 minutes less than 2%) until aircraft traffic reaches a level of approximately 200,000 annual operations. The current level of annual operations is 130,000.
3. The addition of the fifth runway creates a runway system which provides good levels of service until the annual traffic reaches a level of approximately 270,000 annual operations, or more than double the current level.
4. With the addition of the fifth runway, the center runway (which presently has noise problems) would not be used at current levels of traffic. If it is used only at peak times, the percentage of annual operations on this runway remains very small until an annual level of over 200,000 operations is reached.
5. The crossing problem (caused by aircraft which use the fifth runway having to cross the center runway) is not severe, and has been successfully handled at busy U.S. airports. At peak times when all three runways are used, the average wait for a crossing is less than 1 minute with the average number of waiting aircraft less than one half. The maximum number of aircraft waiting to cross ever observed will be less than four during the peaks of these busy periods.

RESEARCH ACTIVITIES: Models and Applications

Student Reports

P. DERSIN, Sensitivity Analysis of Optimal Static Traffic Assignments in a Large Freeway Corridor, Using Modern Control Theory, SM in OR Thesis, September 1976. Also, M.I.T. Electronic Systems Laboratory Report ESL-R-671, July 1976.

The system-optimized static traffic assignment problem in a freeway corridor network is the problem of choosing a distribution of vehicles in the network to minimize average travel time.

It is of interest to know how sensitive the optimal steady state traffic distribution is to external changes including accidents and variations in incoming traffic.

Such a sensitivity analysis is performed via dynamic programming. The propagation of external perturbations is studied by numerical implementation of the dynamic programming equations.

When the network displays a certain regularity and satisfies certain conditions, it is proved, using modern control theory and graph theory, that the effects of imposed perturbations which contribute no change in total flow decrease exponentially as distance from the incident site increases. The impact of perturbations with nonzero total flow is also characterized. The results confirm numerical experience and provide bounds for the effects as functions of distance.

This study gives rise to theoretical results, used in performing the analysis, but also of a broader interest. Flow conservation in a class of networks can be described by linear discrete dynamical systems in standard form. The controllability of these systems is intimately related to the structure of the network, and is connected with graph and Markov chain theory. When the cost function is quadratic (which is the case in this traffic context), asymptotic properties of the optimal cost and propagation matrix are derived. In addition to proved results, some conjectures are formulated, verified in the numerical experiments.

B.L. GOLDEN, Large Scale Vehicle Routing and Related Combinatorial Problems, PhD in OR Thesis, September 1976.

In this thesis, the author considers modeling, algorithms, implementation, and evaluation for a variety of Vehicle Routing Problems.

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Formulations unifying the mathematical models are discussed, along with several widely used heuristic solution techniques. Modifications and extensions to existing heuristic algorithms for vehicle routing which permit problems involving hundreds of demand points to be solved in a matter of seconds are considered. The results are illustrated with a routing study for an urban newspaper with an evening circulation of about 100,000. The interaction between the routing and scheduling of vehicles is pointed out through this study, and later discussed in detail. Some attempts to evaluate worst-case performance of heuristics using combinatorial arguments are indicated. In addition, a method is presented for estimating the optimal tour lengths for large Traveling Salesman Problems which is based on the Weibull probability distribution.

C.B. TANG, Port Capacity Modeling by GERT and Queueing Network Approaches, SM in OR Thesis, June 1977.

The thesis presents an improved definition and ways to model and compute port capacity. One approach uses an analogy to dam theory whereby a mathematical model can be built to derive the dissipation period and storage level of the storage place. Dissipation period here means the time ships are waiting for cargo 'dissipating' from the storage area lest overflow of the area should occur. This is one of the dependent relationships between ship-apron and storage links. The storage level is the average amount of cargo staying in the storage area. It gives the storage throughput simply by dividing it with the cargo dwelling time.

By using queueing theory, clear definition of capacity and actual throughput can be obtained. The capacity is in fact the service rate of the link and actual throughput is the output rate of that link. To compute the service rate, a GERT model can be used to determine some of the influencing factors such as cycle time of each link and a ship longest hatch time.

Further questions about dependency among links can be solved by using non-systematic-tandem-queue theory. Some measurements of the blocking behavior among those dependent links can then be derived. The queueing network can be analyzed by decomposing it into many tandem queues.

The proposed model can be extended to deal with more general port cases, such as a multipurpose terminal.

RESEARCH ACTIVITIES: Models and Applications

2.3 Industrial and Management Systems

Staff Reports

A.C. HAX, Hierarchical Planning Systems - A Production Application, Computer Assisted Corporate Planning, Proceedings of Symposium sponsored by IBM Research, Bad Homburg, Germany, October 1976.

This paper discusses a hierarchical approach for the development of management decision making support systems. In this approach, higher level decisions impose constraints to lower level actions, and lower level decisions provide the necessary feedback to re-evaluate higher level actions. The development of a hierarchical production planning system is described. The role of computers and mathematical models as managerial aids is critically examined.

A.C. HAX, On the Design of Hierarchical Production Planning Systems, (with G.R. Bitran), Decision Sciences, 8, No. 1, January 1977.

To provide effective managerial support to the decisions related to the production planning and scheduling processes, it is useful to partition this set of decisions in a hierarchical framework. In the resulting system higher level decisions impose constraints to lower level actions, and lower level decisions provide the necessary feedback to reevaluate higher level actions. The purpose of this paper is to suggest optimum procedures to deal with the resulting subproblems, and to analyze the interaction mechanisms among the different hierarchical levels. Computational results are given.

J.D.C. LITTLE, Marketing Issues Related to Waste-Grown Aquatic Foods, (with J.E. Huguenin), Environmental Management, 1, No. 5, June 1977, pp. 433-440.

Are societal wastes all bad? Some of them, including heat from power plants and certain organic wastes, have been demonstrated to be potentially valuable for growing aquatic food organisms. The use of such wastes promises the double benefit of a cleaner environment and an increased food supply. Research and development effort can be expected to solve, for at least some production methods, the technical, economic, and public health problems that currently exist.

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But can food grown using potentially objectionable inputs be successfully marketed? All evidence indicates that regulatory agencies will require a much lower health risk for aquaculture food than "wild" ones and will ensure explicit labeling of potentially controversial inputs. Knowledge about potential consumer reaction to such food products is scanty and mixed. Some waste-grown or waste-containing foods (many water supplies, some farm and aquaculture products) are regularly consumed, but the public has also reacted swiftly against foods incriminated on health grounds (shellfish affected by red tide, cranberries contaminated by pesticide) and has sometimes been polarized by controversies (fluoridation).

Under these circumstances a likely marketing strategy is to concentrate on aquatic organisms that are not directly used for human consumption but can be used for animal food or processed for their extracts. For sea foods that are eaten directly (fish, shellfish), a promising strategy is to take advantage of the quality control possible in aquaculture products to produce premium foods. These can be sold first to the restaurant trade, with direct distribution to preserve maximum freshness, and later to consumers. An interesting possibility between direct and indirect use is use as components of processed and prepared seafoods (fish sticks, fish cakes). Separately and simultaneously a public information campaign can stress the merits and advantages of waste utilization.

J.D.C. LITTLE and J.F. SHAPIRO, A Theory for Pricing Non-Featured Products in Supermarkets, M.I.T. Sloan School of Management Working Paper 931-77, May 1977.

Of the 6,000 products in the average supermarket, a few receive special displays, advertising, and prices in a given week, but the great majority are assigned prices by simple percentage markups within category, adjusted, if necessary, for competitive conditions and special price endings. Missing is any direct consideration of actual customer price response.

The advent of the Universal Product Code and inexpensive, machine readable sales data by individual item promises to make possible the widespread determination of customer price response by in-store experiment. This in turn, opens up the possibility of developing and implementing a more adequate theory for setting prices.

Yet, stores should not set price in a simple profit-maximizing way based on in-store measurements of price response. The reason

is that the customer may pay a high price once and then not come back to the store, thereby creating a small short term gain and a large long term loss.

A two-stage theory addresses this issue by postulating that customers once in the store purchase goods to maximize their utility. This determines observable in-store customer price response. The store then maximizes its profit subject to a constraint on customer utility delivered. The level of the constraint becomes a policy parameter that determines, in part, the attractiveness of the store to the customer.

It is shown that under this theory, the store can set prices of non-featured items using a formula containing only empirical measurements and a single policy parameter for all items. It is further shown that the prices are efficient in the sense that for a given level of store profit no other set of prices will permit higher consumer utility and, conversely, for a given level of customer utility, no other prices will permit higher store profit.

Student Reports

A.S. KANODIA, Material Requirements Planning: A Study, M.I.T. Operations Research Center Technical Report No. 128, November 1976.

Inventory management techniques have gained in importance in the past few years because of the cash crunch being faced by most companies. Material Requirements Planning (MRP) is gaining rapidly in popularity, especially after the APICS (American Production and Inventory Control Society) MRP Crusade. The technique is being presented as if it were the cure for all ills. The purpose of this report is to identify a number of issues that are relevant to MRP and, wherever possible, to propose an approach. Another purpose is to study how firms tackle these issues and to present real-life implementation characteristics. With this in mind, seven firms were interviewed personally. The study concludes that the issues are largely unresolved in industry and whatever benefits are accruing are mostly due only to better timing information generated by the explosion process rather than any other formal procedures. It follows that further benefits are achievable if the issues are tackled in a scientific manner.

J.W. WEXLER, A Methodology for Configuring Distributed Real-Time Microcomputer Systems, with Application to Inertial Navigation Systems, SM in OR Thesis, June 1977.

A methodology for configuring distributed real-time microcomputer systems is developed. This methodology is intended for use in

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the early stages of the design process. The configuration problem consists of matching software components to hardware components. The desired assignment is one that accomplishes its required function, obeys configuration constraints (of both physical and timing natures) and is optimal under some criterion. The thesis therefore centers around the development of a conceptual model which allows the mathematical expression of the constraints, interrelationships, and objectives in configuring real-time systems. Such a mathematical formulation is developed, in the form of a mathematical programming problem. A solution algorithm is suggested; this algorithm utilizes a master/subproblem decomposition and a branch-and-bound algorithm. The methodology and algorithm are demonstrated on a test case; this test case is the inertial navigator problem for aircraft.

2.4 Energy

Staff Reports

J.F. SHAPIRO, Sensitivity Analysis of the Brookhaven Energy System Optimization Model, (with D.E. White and D.O. Wood), M.I.T. Operations Research Center Working Paper OR 060-77, January 1977.

Sensitivity analyses were performed on the levels of primary energy supplies of the Brookhaven Energy System Optimization Model of the U.S. energy sector. Nonlinear supply functions were incorporated and the extended model was solved using generalized linear programming.

J.F. SHAPIRO, Decomposition Methods for Mathematical Programming/Economic Equilibrium Energy Planning Models, M.I.T. Operations Research Center Working Paper OR 063-77, March 1977.

A number of energy planning models have been proposed for combining econometric submodels which forecast the supply and demand for energy commodities with a linear programming submodel which optimizes the processing and transportation of these commodities. We show how convex analysis can be used to decompose these planning models into their econometric and linear programming components. Various methods are given for optimizing the decomposition, or equivalently, for computing economic equilibria for the planning models.

RESEARCH ACTIVITIES: Models and Applications

Student Reports

R. CHEN, Nuclear Reactor Rescheduling Study, SM in OR Thesis, February 1977.

A mathematical programming model for solving the problem of minimizing fresh fuel consumption in a light water moderated reactor (LWR) was formulated and analyzed.

The model divides the LWR into five spatial zones, each of which has a fixed energy and overall effective multiplication factor requirement, alongside a capacity constraint. Fuel assemblies are introduced into the zones and are subjected to successive reshuffling throughout the reactor during its lifetime, with the objective of rescheduling studies being the determination of the best set of assembly paths which would bring about the system requirements and simultaneously minimize the amount of fuel required, or equivalently, the total number of assemblies required.

2.5 Economic Systems

Staff Reports

T. HANSEN, A Procedure for Determining Optimal Subsidies and Economic Activity Levels in an Economically Depressed Area, M.I.T. Operations Research Center Technical Report No. 132, May 1977.

In many developed countries, there are areas with serious employment problems. Factor prices in such economically depressed areas are typically determined outside the area. Wage rates, for example, are given by nationwide bargaining by labor unions and are typically in excess of marginal productivity of labor in the depressed area. Economic activity in a depressed area is mainly undertaken by private entrepreneurs, who cannot operate without a subsidy of some kind.

A goal of public policy in the depressed area is full employment. This goal may be achieved either by expanding the public sector or by stimulating economic activity in the private sector through subsidies. The government seeks full employment at the lowest

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possible cost, the cost being the sum of total subsidies to the private sector and the net cost of the expanded public sector. The planning problem is formulated as a mixed integer programming problem. A solution procedure is suggested. The paper contains a constructed numerical example to illustrate the application of the solution procedure.

Student Reports

S. PARIENTE, Optimization Models for Planning Economic Development, M.I.T. Operations Research Center Technical Report No. 130, April 1977.

In recent years, more and more countries have experimented with quantitative methods as a way to design short term and long term plans, and to evaluate the impacts of investment and other policies on the future development of their economies. Optimization models have proved useful in several fields of economics, such as economic growth and development planning, urban and regional economics, agricultural and energy economics, etc. The purpose of this paper is to formulate optimization models that can be applied fruitfully for economy-wide planning, sectoral planning, and project evaluation. It is an attempt at synthesizing the different models encountered in the literature, and at describing some of the difficulties inherent to this approach.

F. SULTAN, A Simulation Model of Population and Agricultural Growth in a Developing Country, SM in OR Thesis, June 1977.

In recent years, the population issue has been the subject of much debate and discussion. The World Population Conference at Bucharest (1974) highlighted the different views on the subject of population, particularly the population of the developing countries of the Third World.

Although the views expressed were very diverse and, at times, diametrically opposed, there was a general consensus that the population issue could not be studied in isolation from the socio-economic conditions. This work will try to study the interrelationship of population and development and will concentrate primarily on agricultural growth in a developing country.

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The analysis shows that unless the standard of living of the rural people in a developing country is increased many times the present, it may not be possible to bring down the population growth rate in the rural areas.

In an agrarian economy unless a just, equitable distribution of wealth is realized, unless labor intensive techniques are employed to harness the energy of the masses, and unless a restricting of the socio-economic structure through massive land reforms takes place, there is not much hope that birth rate and death rates can be lowered by agricultural development alone.

RESEARCH ACTIVITIES

3. Computation

Staff Reports

R.E. WELSCH, Graphics for Data Analysis, Computers and Graphics, 2, 1976, pp. 31-37.

In recent years, graphics has become an essential part of modern data analysis. It is particularly useful for interactive data analysis. This paper describes a system called CLOUDS which is designed to make available on inexpensive storage tube terminals a wide range of graphics tools related to data analysis, economics, and management science. The system can be accessed by nonprofit organizations via the National Bureau of Economic Research computer network.

R.E. WELSCH, On Evaluating Interactive Statistical Program Packages, (with P. Velleman), Communications in Statistics, B5, 1976, pp. 197-205.

Most statistical computing for data analysis has come to depend upon statistical program packages. In recent years, interactive computing has become widespread both on large time-sharing systems and on mini-computers. This paper identifies ways in which interactive statistical software packages differ from batch-oriented software and discusses evaluation considerations pertaining specifically to interactive packages.

Student Reports

A.A. ASSAD, Multicommodity Network Flows--Computational Experience, M.I.T. Operations Research Center Working Paper OR 058-76, October 1976.

This paper reports computational results with two algorithms for the linear multicommodity flow problem--a price-directive algorithm based on Dantzig-Wolfe decomposition for block-angular systems and a resource-directive algorithm based on subgradient optimization. It was found that the performance of the price-directive algorithm was markedly superior. The code was then used to solve a multi-fleet air routing problem. The results show this to be a very efficient approach to routing problems.

III. EDUCATIONAL ACTIVITIES

A. Subjects Offered by Operations Research Center Staff 1976-77

<u>Subject Number</u>	<u>Subject Title</u>	<u>Instructor</u>	<u>Term</u>	<u>Enroll- ment</u>
1.203	Transportation Supply Models	A.R. Odoni	Spring	21
6.041	Probabilistic Systems Analysis	A.W. Drake	Summer	43
6.041	Probabilistic Systems Analysis	A.W. Drake	Fall	178
6.041	Probabilistic Systems Analysis	A.W. Drake	Spring	212
6.262	Advanced Markov Models and Their Applications	A.W. Drake and R.C. Larson	Spring	29
6.281J 11.526J 15.961J 16.76J	Analysis of Urban Service Systems	A.I. Barnett, R.C. Larson and A.R. Odoni	Spring	35
6.431	Applied Probability	A.W. Drake	Summer	16
6.431	Applied Probability	A.W. Drake	Fall	21
6.431	Applied Probability	A.W. Drake	Spring	15
15.523	Program Evaluation	R.C. Larson and M. Rein	Spring	15
15.053	Introduction to Management Science	J.D.C. Little	Fall	60
15.061	Mathematics for Management I	A.I. Barnett	Fall	59
15.062	Mathematics for Management II	R.E. Marsten	Fall	59

EDUCATIONAL ACTIVITIES: Subjects Offered

<u>Subject Number</u>	<u>Subject Title</u>	<u>Instructor</u>	<u>Term</u>	<u>Enroll- ment</u>
15.063J 18.457J	Statistics for Model Building	H. Chernoff and R.E. Welsch	Spring	40
15.065	Decision Analysis	G.M. Kaufman	Fall	47
15.073J 18.445J	Stochastic Processes	A.I. Barnett	Spring	10
15.081	Mathematical Program- ming	T. Hansen	Fall	46
15.081	Mathematical Program- ming	R.E. Marsten	Spring	34
15.083	Combinatorial Opti- mization	R.E. Marsten	Spring	28
15.084J 6.251J	Mathematical Program- ming and Discrete Time Optimal Control	S.K. Mitter and J.F. Shapiro	Fall	31
15.099	Seminar in Management Science	J.D.C. Little	Fall	8
15.099	Seminar in Management Science	J.D.C. Little	Spring	6
15.781	Capacity Planning: Production and Distri- bution Systems	J.F. Shapiro	Fall	7
15.791	Operations Planning and Control	A.C. Hax	Spring	30
15.825	Marketing Models	G.L. Lilien and J.D.C. Little	Spring	4
16.601	Reading Course in Probability	A.R. Odoni	Fall	4

EDUCATIONAL ACTIVITIES: Subjects Offered

<u>Subject Number</u>	<u>Subject Title</u>	<u>Instructor</u>	<u>Term</u>	<u>Enroll- ment</u>
16.701	Principles of Systematic Policy Analysis	A.R. Odoni	Fall	16
16.702	Seminar in Systematic Policy Analysis	A.R. Odoni	Spring	8

EDUCATIONAL ACTIVITIES

B. Operations Research Seminars

The Operations Research Center seminar series provides an opportunity for students and faculty to hear speakers on operations research from inside and outside M.I.T. All seminars are open to the M.I.T. community and the public. They are often general in content and so provide undergraduates and beginning graduate students with a perspective on O.R. activity.

Oded Berman and Jeremy A. Bloom were the Seminar Coordinators for the year.

October 19	Prof. Terje Hansen Visiting Professor Sloan School of Management M.I.T. Cambridge, Massachusetts	A Procedure for Determining Optimal Subsidies of Capital and Labor in Order to Maintain Full Employment in Depressed Areas
November 18	Prof. Albert W. Tucker Department of Mathematics Princeton University Princeton, New Jersey	Samples of Combinatorial Mathematics
December 7	Prof. Gordon P. Wright Visiting Professor Amos Tuck School Dartmouth College Hanover, New Hampshire	Some New Results in Purchase Timing and Brand Selection
January 6	Prof. Arnolando C. Hax Sloan School of Management M.I.T. Cambridge, Massachusetts	The Design of Hierarchical Production Planning Systems
January 11	Dr. Steven Robinson Manager Database Technology Group CACI, Inc. New York, New York	Collecting Data for Stochastic Network Systems

EDUCATIONAL ACTIVITIES: O.R. Seminars

January 13	Prof. Joseph Ferreira, Jr. Department of Urban Studies and Planning M.I.T. Cambridge, Massachusetts	Auto Insurance Rate Making
January 18	Mr. Ivan Stern Reentry and Environmental Systems Division General Electric Philadelphia, Pennsylvania	Applications of Opera- tions Research at the G.E. Reentry and Environmental Systems Division
January 20	Prof. Philip M. Morse Department of Physics M.I.T. Cambridge, Massachusetts	Opportunities for Operations Research in Developing Coun- tries
January 25	Prof. Terje Hansen Visiting Professor Sloan School of Management M.I.T. Cambridge, Massachusetts	An Aggregate Cost Func- tion for the Norwegian Industrial Fisheries: Its Implications for Public Policy with Respect to the Purse Seiner Fleet
February 10	Dr. Costis Toregas Assistant to the President Public Technology, Inc. Washington, D.C.	Operations Research with Local Governments; Some Hints to Increase Chance of Success
March 10	Prof. Melvin F. Shakun Graduate School of Business Administration New York University New York, New York	Design of Purposeful Systems
March 24	Dr. Alan J. Goldman Chief, Operations Research Applied Mathematics Division National Bureau of Standards Washington, D.C.	Some Useful Approxi- mations in Optimal Facility Location

EDUCATIONAL ACTIVITIES: O.R. Seminars

April 7	Prof. Amedeo R. Odoni Department of Aeronautics and Astronautics M.I.T. Cambridge, Massachusetts	Figuring Out the Capacities of Airports
April 14	Prof. Arnold I. Barnett Sloan School of Management M.I.T. Cambridge, Massachusetts	Crime and Capital Punishment
April 21	Prof. Floyd J. Gould Graduate School of Business University of Chicago Chicago, Illinois	Recent Research in Complementary Pivot Theory
May 5	Prof. Bennett Fox Departement d'Informatique Universite de Montreal Montreal, Quebec	Shortest Route Methods: Reaching, Pruning, and Buckets

EDUCATIONAL ACTIVITIES

C. O.R. Theses Completed

Author

Supervisor

R.C. CHEN, "Nuclear Reactor Rescheduling Study," SM, February 1977.

J.F. Shapiro

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T.L. MAGNANTI, "Traffic Equilibrium on a Congested Network," Dutch National Optimization Seminar, Delft, The Netherlands, May 1977.

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MASSACHUSETTS AUTOMOBILE RATING AND ACCIDENT PREVENTION BUREAU
"Evaluating the Consumer's Interest in Merit Rating Plans"

NATIONAL SCIENCE FOUNDATION
"Computer Science and Statistics: Ninth Annual Symposium on the Interface"

U.S. ARMY RESEARCH OFFICE
"Basic Studies in Combinatorial and Nondifferentiable Optimization"

U.S. DEPARTMENT OF TRANSPORTATION
"Transportation Network Analysis and Decomposition Techniques"

U.S. OFFICE OF NAVAL RESEARCH
"Multilevel Logistics Organization Models"

U.S. OFFICE OF NAVAL RESEARCH
"Computer Science and Statistics: Ninth Annual Symposium on the Interface"

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"Blood Donor Motivation and Recruitment"

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